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Effects of Selected Herbicides on Perennial Grasses and Water Pollution under Tropical, High Rainfall Condition

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EFFECTS OF SELECTED HERBICIDES ON PERENNIAL GRASSES AND WATER POLLUTION UNDER TROPICAL, HIGH RAINFALL CONDITIONS

by

Richard L. Chase

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Effects of Selected Herbicides on Perennial Grasses

and Water Pollution under Tropical,

High Rainfall Conditions

by

Richard L. Chase, Master of Science

Utah State University, 1972

Major Professor: Dr. John O. Evans
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The following herbicides were evaluated for their effect on perennial grasses and water pollution in El Salvador, Central America: MSMA (monosodium methanearsonate), DSMA (disodium methanearsonate), cacodylic acid (hydroxydimethylarsine oxide), paraquat (1,1'dimethyl-4,4'-bipyridinium ion), dalapon (2,2-dichloropropionic acid), amitrole (3-amino-s-triazole), atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine), diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea), and karbutilate (m-(3,3-dimethylureido)phenyl-t-butylcarbamate). The herbicides were sprayed on drainage channels at different dosage levels. Some plots received one application, others received two, and still others received three applications.

All herbicides except atrazine effectively controlled perennial grasses. Cacodylic acid was the most effective contact chemical, with dosage levels of 7 and 10 kg/ha achieving 77 percent control of the grasses after two applications. Four and 6 kg/ha of amitrole produced 67 percent during the same period, but control of amitrole

then increased while control of cacodylic acid decreased.

After three applications, 5 kg/ha of MSMA yielded 88 percent control. MSMA was more effective than DSMA or dalapon. No significant increase in control was obtained by alternating dalapon and organic arsenicals.

A single application of 12 kg/ha of diuron and karbutilate effectively controlled perennial grasses for 6 weeks.

During the dry season, a single application of MSMA at 5 kg/ha, cacodylic acid at 10 kg/ha, and paraquat at 2 kg/ha each yielded over 70 percent control after 8 days.

Water samples were taken during rainstorms that occurred shortly after application of diuron, MSMA, and cacodylic acid. The highest concentration of diuron was 1.8 ppm. Samples containing MSMA and cacodylic acid were analyzed for arsenic, and in no case was the concentration greater than .5 ppm. These low concentrations likely would not be hazardous to crops, animals, or fish.

(67 pages)

INTRODUCTION

One of the most serious problems that exist in tropical, high rainfall areas is the rapid growth of perennial grasses. They grow vigorously and regenerate more quickly because of abundant water, heat, and high light intensity. In many areas, the only means of control is cutting the weeds with machetes, which may be required once each month (Figure 1).

According to Furtick (1967) most of the research on weed control has been limited to the temperate zones of Europe, North America, and similar regions. It has only been in the past 5 or 6 years that any appreciable amounts of herbicides have been marketed in tropical regions. Furtick (p. 21) states that "Yield increases resulting from improved weed control alone would be enough to more than solve the current food needs and bring about an agricultural surplus production in many food-short tropical areas." Only if one has visited these tropical areas can he truly comprehend the significance of Dr. Furtick's statement.

Holm (1971) proposed that more energy is expended in weeding than for any other human task. He indicated that as one travels around the world, he may have the impression that one-half of the world's men and women are in the fields, moving slowly, and silently weeding. We could help these people, he suggests, by helping them control their weeds. This would allow them to do other things which may be more worthwhile, and at the same time increase productivity.

The purpose of this study was to apply selected herbicides on drainage channels in order to find an effective means of controlling perennial grasses, and also to study the effects of these herbicides under high rainfall conditions with regard to phytotoxicity and water movement.

There is considerable interest today concerning the polluting of our environment. High rainfall following application of herbicides may result in the movement of the applied herbicides which would contaminate the water in the channel. An integral part of this study was to sample the water during rainstorms to determine to what extent herbicides enter the water.

Figure 1. Ditchbank weed control with the machete

REVIEW OF LITERATURE

There are three areas of concern in this research: herbicides, environmental factors, and water pollution.

Herbicides

Johnsongrass (Sorghum halepense) is a very serious perennial weed and thrives under tropical conditions. It is a good example of the perennial grasses that exist in the tropics. Banks of drainage ditches are primary sources of dissemination.

Several cultural and chemical means have been used in controlling johnsongrass. Soil sterilants that kill all the vegetation are undesirable since the soil on the ditchbanks may erode severely during the heavy rains. Millhollon (1969) reported that five post-emergence applications of dalapon (2,2-dichloropropionic acid) at 7.4 lb/A or MSMA (monosodium methanearsonate) at 3.6 lb/A controlled johnsongrass as effectively as 600 lb/A of sodium chlorate, the standard treatment. The plants were approximately 14 inches tall on the first application and thereafter applications were made when the plants were about 24 inches tall. Three applications of MSMA or dalapon substantially reduced the stand. Millhollon further noted that desirable characteristics of MSMA and dalapon are: they are not limited to a specific time of application, cost can be reduced by applying them as spot treatments, and they are better adapted than soil-applied treatments for controlling johnsongrass seedlings where ditchbanks are covered with more herbaceous weeds and vines.

An important observation that Millhollon made was that control involved two distinct steps: initial control of established johnsongrass, and annual control of the new seedlings.

McWhorter (1966) reported that dalapon is often ineffective on mature johnsongrass and also in dry weather. DSMA (disodium methanearsonate), however, seems to have a greater phytotoxicity in dry weather, and kills the topgrowth of mature johnsongrass. It would seem likely that alternating DSMA and dalapon in many seasonal control programs would be worthwhile. McWhorter suggested therefore, that DSMA could be used to kill topgrowth and dalapon could be used on the regrowth.

Hamilton (1969) found that MSMA and DSMA were the most effective herbicides in controlling established, space-planted strains of johnsongrass. Six applications of either herbicide with 3 lb/A or more of either killed the grass. Hamilton also found that DSMA combined or alternated with dalapon reduced the effectiveness of the organic arsenical, in opposition to what McWhorter suggested. He also found that MSMA was more effective than DSMA, confirming a report made by Lucas (1961). Kempen (1966), also concluded that MSMA was more effective than either DSMA or dalapon.

McHenry, Smith, and Yeager (1970) observed that where MSMA at 4 lb/A and dalapon at 15 lb/A were applied four times over a period of one year, MSMA resulted in a more rapid stand reduction than dalapon.

Several other researchers, including Hogan (1966), Jensen (1969), and Hodgson (1968) have found dalapon and organic arsenicals to be

effective in controlling Sorghum halepense or other perennial grasses.

According to Hamilton (1969), there is a wide range of rates of organic arsenicals which will control johnsongrass. Higher rates require fewer applications but more herbicide. Lower rates use less herbicide but additional applications are needed and the costs of labor and surfactant are increased.

Cacodylic acid (hydroxydimethylarsine oxide) has been used in defoliation. It has been used in Vietnam, primarily for the control of grasses surrounding military installations (Minarik, 1968). The compound has been reported by Sachs and Michael (1971) to be more phytotoxic than MSMA when foliar applied. In their research they found no indication that cacodylic acid or MSMA was demethylated to form inorganic arsenicals or reduced to trivalent arsenic compounds.

Bovey, Dowler, and Diaz-Colon (1969) found that cacodylic acid was a very effective defoliant on guava (Psidium guajava) within 2 weeks after treatment, but that growth-regulator-type herbicides were more effective 1 month after spraying.

Amitrole (3-amino-s-triazole) has been an effective herbicide in the control of perennial grasses. Reed canarygrass (Phalaris arundinacea) is particularly well adapted to wet soils, and grows well on banks or irrigation ditches. Hodgson (1968) reported that amitrole at 5 lb/A controlled reed canarygrass for 2 months. Jensen (1969) reported that amitrole at 8 lb/A sprayed at monthly intervals effectively controlled Cynodon dactylon.

In California, amitrole is used for general weed control on ditch-banks. The recommended rate is 4-8 lb/A. The most important weeds

are Sorghum halepense, Cynodon dactylon, and Convolvulus sp. (Hogan, 1966).

Tideman (1966) reported that Paspalum, Juncus, and Cyperus sp. are controlled in Australia with 3-6 kg/ha of amitrole with half rates applied 6 weeks later. According to Bill (1969) about 40 percent of the total expenditure for chemical control of aquatic weeds in Australia was accounted for by the treatment of Paspalum distichum with amitrole.

Since its discovery in the 1950's, paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) has been used for selective and nonselective terrestrial and aquatic weed control. It has been used extensively for desiccation and defoliation. Paraquat is extremely fast acting, even at low concentrations.

Jeater and McIlvenny (1960) have shown that paraquat controls perennial grasses. They used it both alone and in combination with residual herbicides. Putnam and Ries (1968) reported that paraquat defoliated Agropyron repens for 25-30 days with applications of 1 lb/A. Applications were more effective when made just prior to darkness than at midday.

Paraquat is used in New Zealand to maintain weed-free road shoulders. The main weeds are Paspalum sp. and Digitaria sanguinalis. Paraquat is used as a knockdown herbicide; and diuron, simazine, and bromacil as residual herbicides (McFarlane, 1967).

Kasasian (1967) reported that paraquat destroys the topgrowth of Cyperus rotundus, but that regrowth will occur in about 1 week.

Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) and diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea) are effective

herbicides on grasses. LeBaron (1962) demonstrated that atrazine depletes the food reserves in quackgrass, and that cultivation was not necessary to maintain reduction of rhizome root reserves.

In California, weed control on irrigation channels in 1957 was based on the use of high rates in autumn and winter of soil-acting herbicides including atrazine at 5-12 lb/A and diuron at 5-12 lb/A. The most important weeds included Cynodon dactylon, Sorghum halepense, and Rumex sp. (Hogan (1966).

Tideman (1966) reported that diuron at 25 kg/ha applied to ditchbanks in Australia maintained almost bare soil as long as 2 years.

In the USSR, Spiridonov (1966) reported atrazine and diuron were used to control Paspalum, Cyperus, Polygonum sp., and other weeds. Atrazine at 10-20 kg/ha and diuron at 10-40 kg/ha were very effective and residual effects lasted about 2 years.

Karbutilate (m-(3,3-dimethylureido)phenyl-t-butylcarbamate) is a relatively new herbicide designed for use on non-crop land. According to Harris (1969), in 4 years of trials, this compound proved effective for total weed control at 8-12 lb/A for fibrous-rooted perennial weeds. He indicated that 15-25 lb/A may be necessary for perennial weeds with extensive underground rootstocks.

In Australia, karbutilate at 10 kg/ha was applied to mature populations of grasses. At the end of the 6-month period, during which time 531 mm of rain was recorded, complete control was obtained (Lugg and Smith, 1970).

Environmental Factors

The herbicide recommendations given in a temperate climate cannot be directly applied to a tropical region. There is usually large gradients between the areas in rain, temperature, relative humidity, and soil types. These factors have a great bearing on the effectiveness of herbicides.

Rain

The effects of rain on herbicide response depend greatly on the amount, intensity, and its incidence in time. Rain during or immediately following spraying will, in most cases, wash the herbicide off the leaves and reduce or nullify its effectiveness. The degree to which this occurs depends not only on the quantity, but also the intensity of the rain. Aslander (1950) observed that as little as 0.2 mm rain during spraying nullified the effects of 2,4-dichloro-phenoxyacetic acid (2,4-D) on perennial weeds. In other trials, 0.2 mm rain 1 hour after spraying reduced the effect by 50 percent.

If rain occurs a few days before spraying, leaf wettability may be increased, reported Hammerton (1967). Herbicide susceptibility should also increase due to the mechanical damage to the wax structures of the leaf surface.

The amount of rain following herbicide application may determine the amount of leaching and degradation. In areas of rainfall less than 20 inches, Burnside, Fenster, and Wicks (1963) reported carry-over of substituted urea compounds to be a problem. In areas of high rainfall, the reverse may occur, i.e. carry-over is not sufficient to effectively control weeds. In the Zapotitan Valley, average rainfall

is 1681 mm a year (Table 1, Servicio Meteorologico National, 1972).

Table 1. Average rainfall (mm) in the Zapotitan Valley[a]

Month	Average rainfall per month	Maximum amount per month	Minimum amount per month
Jan	6	41	0
Feb	2	18	0
Mar	9	62	0
Apr	66	228	8
May	198	339	71
June	278	480	156
July	328	516	202
Aug	267	431	164
Sep	302	525	166
Oct	179	299	54
Nov	39	117	0
Dec	7	87	0
Year	1681	3143	820

[a]Rainfall measured over a period of 24 years.

Temperature

Temperature conditions during and following spraying will affect the plant and also the chemical properties of the herbicide. Hammerton (1967) and others have reported increased herbicide penetration and weed susceptibility with higher temperatures.

An item of major importance in tropical areas is the length of time residual chemicals remain active. In temperate regions, atrazine and diuron, for example, may last one or two years. With high temperatures all year, however, they may last only a fraction of that time. The average yearly temperature in the Zapotitan Valley is 23.9 C (Table 2, Servicio Meteorologico National, 1972).

Table 2. Average temperatures (C) in the Zapotitan Valley

Month	Average maximum daily temperature	Average daily temperature	Average minimum daily temperature
Jan	32.0	22.6	13.5
Feb	33.3	23.4	14.5
Mar	34.4	24.6	15.9
Apr	34.6	25.6	18.0
May	33.2	25.2	19.1
June	31.5	24.3	19.3
July	31.7	24.2	18.8
Aug	32.0	24.3	19.2
Sep	31.0	23.9	19.2
Oct	30.7	23.5	18.4
Nov	30.8	22.7	16.0
Dec	31.1	22.2	14.2
Year	32.2	23.9	17.2

McCormick and Hiltbold (1966) found that the atrazine decomposition rate doubled with each 10 degree rise in temperature from 10 to 30 C. Diuron decomposition approximately tripled with each 10 C rise in temperature.

Relative Humidity

Relative humidity affects water stress, stomatal opening, and cuticular permeability (Hammerton, 1967). In general, high relative humidity during and after spraying will increase penetration and absorption of herbicides, and, presumably, the killing of the weed. Table 3 gives the average relative humidity in the Zapotitan Valley (Servicio Meteorologico National, 1972).

Table 3. Average relative humidity (%) in the Zapotitan Valley[a]

Month	Relative humidity	Month	Relative humidity
Jan	69	July	82
Feb	68	Aug	82
Mar	67	Sep	85
Apr	71	Oct	82
May	78	Nov	76
June	84	Dec	72

[a]Average relative humidity measured over 22 years.

Soil Type

Soil type has a pronounced effect on herbicidal movement and phytotoxicity. As soon as an herbicide is applied to soil, it becomes subject to several processes which promote inactivation. These processes are influenced by several soil properties including type and amount of clay, structure, organic matter, texture, temperature, moisture, and pH. Sheets (1964, p. 31) reported that differences in soil properties, microorganisms, climate, and physical and chemical properties of herbicides account for variations in persistence from region to region.

McCormick and Hiltbold (1966), working with atrazine and diuron, found that both herbicides were inactivated more readily in loamy soil than in a clay loam, and atrazine was inactivated much more readily than diuron.

Water Pollution

Mullison (1970, p. 738) reports "There is little evidence that herbicides from agronomic or industrial usage are reaching or accumulating in our water supplies in amounts to cause a pollution problem."

The Senate Select Committee on Water Resources has stated that "water pollution from agricultural chemicals is not as extensive as some would lead us to believe" (Wadleigh, 1967, p. 27).

Many studies have been made to determine the effects of herbicidal residues in water. The low concentrations that are observed following application of herbicides likely would not be hazardous to crops or animals.

In spite of the many benefits from agricultural chemical usage, any biologically-active chemical implies a potential hazard that should be evaluated. In general, herbicides are of a relative low order to toxicity and the potential for these being a source of pollution is minimized.

There is a potential hazard dealing with ditchbank weed control in the tropics that needs to be evaluated. If herbicide applications are followed by heavy, intense rainfall, large amounts of herbicide may be washed into the channel. During May through October (the rainy season), there is an average of about 22.5 days in which more than 2.5 cm of rain fall in the Zapotitan Valley (Table 4).

Diuron. Diuron is reported to be one of the best herbicides for use in water supply reservoir areas. Its LD_{50} for humans is approximately one-fifth that of 2,4-D (Maloney, 1958). According to Chancellor (1958), concentrations up to 180 ppm are non-poisonous to man and livestock.

Oborn and Bartley (1954) found that concentrations of 7.4 and 18.7 ppm in irrigation water killed tomatoes after 10 days and injured cotton plants after 41 days.

Diuron has a relatively low acute toxicity to fish. A 96-hour LD_{50} value of 8,700 mg/L was recorded for bluegills (*Lepomis machrochirus*) averaging 0.78 g in weight (Sills, 1964).

Organic arsenicals. MSMA and cacodylic acid contain elemental arsenic at 20.2 and 12.5 percent respectively. The use of organic arsenicals has been debated because of the build-up of toxic levels of arsenic with time.

Table 4. Average number of days per month in the Zapotitan Valley with more than 10 mm[a] of rain and more than 25 mm[b]

Month	10 mm or more	25 mm or more
Jan	0	0
Feb	0	0
Mar	0	0.1
Apr	3.0	0.8
May	7.0	2.5
June	9.0	4.5
July	12.0	4.7
Aug	10.0	3.8
Sep	10.0	4.4
Oct	6.0	2.6
Nov	1.0	0.5
Dec	0	0

[a]Data taken over a 17-year period.
[b]Data taken over a 48-year period.

Normal human blood contains between 0.2 to 1.0 mg/L of arsenic. In 1946, the U. S. Public Health Service Drinking Water Standards established an arsenic limit of 0.05 mg/L (United States Department of Health, Education and Welfare, 1962).

McKee and Wolf (1963) reported that the presence of excessive soluable arsenic in irrigation water reduced the yield of crops, the main effect appearing to be the destruction of chlorophyll in the foliage. Plants grown in water containing 1 mg/L of arsenic trioxide show a blackening of the vascular bundles in the leaves. They reported a lethal dose of arsenic for animals to be approximately 20 mg per animal pound. It may be toxic to certain fish if they are exposed to levels greater than 1 ppm for several days.

Because of the foregoing information the limit for arsenic in irrigation water, stock water, and for fish and aquatic life has been set at 1.0 mg/L.

MATERIALS AND METHODS

This research was conducted in the Zapotitan Valley in El Salvador, Central America. An agricultural research project of about 4,500 hectares is located there. The elevation is approximately 460 meters.

On both sides of the roads throughout the project are drainage ditches used to carry the water during heavy rains from the fields to larger canals (Figure 2). These ditches range from approximately 1 to 2.5 meters in depth, and are heavily infested with perennial grasses. The main grasses are Panicum purpurascens, Cynodon dactylon, Digitaria sanguinalis, Eleusine indica, and Paspalum sp.

Figure 2. Typical drainage ditch heavily infested with perennial grasses

The soil is primarily a sandy loam with sand, silt, and clay content averaging 56, 32, and 12 percent respectively. The organic matter content averaged 1.8 percent and the pH is around 7.6.

The experimental design was a randomized block, each ditchbank being a different replication, of which there were four. Plots were 20 meters long by approximately 3.5 meters wide. Between each plot was a 10 meter check plot. Treatments were made using a CO_2 pressurized small plot sprayer with #8003 nozzle tips. Pressure was maintained between 30-35 psi and approximately 500 liters of water were applied per hectare.

Visual evaluations were taken of the plots and injury index values were given: 1-3 indicates degrees of slight injury; 4-6, moderate injury; 7-9, heavy injury; and 10, complete kill. These values can be multiplied by 10 to give an estimate of percent control.

Several herbicides have been recommended for ditchbank weed control. The following were used in this research: MSMA, DSMA, cacodylic acid, and paraquat as contact herbicides; dalapon and amitrole as translocated herbicides; and atrazine, diuron, and karbutilate as residual herbicides.

In all of the experiments a non-ionic surfactant was added at .5 percent to those herbicides that had none in the product.

Two distinct seasons exist in El Salvador: the dry season beginning in November and lasting through April, and the rainy season which is generally from May through October.

Rainy Season Experiments

Contact, translocated, and residual herbicides--a single application

Table 6 shows all the treatments that were applied in this experiment. Applications began on July 7, 1971. Evaluations were made after 15 days.

Contact and translocated herbicides--2 applications

The same plots that were treated in the previous experiment were retreated with the same herbicides 21 days after the first application, with the exception of the residual herbicides, which were applied only once. Four additional treatments were made in which dalapon and organic arsenicals were alternated 21 days after a previous application. Table 5 gives the alternated treatments. Only the first and second applications apply to this experiment. Evaluations were made 15 days after the second application.

Table 5. Four treatments in which dalapon and organic arsenicals were alternated

First Application	kg/ha	Second Application	kg/ha	Third Application	kg/ha
Dalapon	5	MSMA	4	Dalapon	5
MSMA	4	Dalapon	5	MSMA	4
Dalapon	5	DSMA	4	Dalapon	5
DSMA	4	Dalapon	5	DSMA	4

Table 6. Treatments of contact, translocated, and residual herbicides

Herbicide	Grams of milliliters per treatment	kg/ha
MSMA	30.4	3.0
	41.0	4.0
	51.0	5.0
DSMA	27.0	3.0
	36.0	4.0
	45.0	5.0
Cacodylic acid	85.0	3.5
	172.0	7.0
	240.0	10.0
Dalapon	43.2	5.0
	64.0	7.5
	86.0	10.0
Amitrole	122.0	4.0
	182.0	6.0
	244.0	8.0
Atrazine	36.4	4.0
	73.0	8.0
	110.0	12.0
Diuron	36.4	4.0
	73.0	8.0
	110.0	12.0
Karbutilate	36.4	4.0
	73.0	8.0
	110.0	12.0

Dalapon and organic arsenicals--3 applications

Dalapon, MSMA, and DSMA were applied a third time to the plots 15 days following the second application. (See Table 5 for the third application of the alternating herbicides.) Evaluations were made 15 days later.

Amitrole and cacodylic acid--2 applications

Only two applications were made of the treatments with amitrole and cacodylic acid. The second was made 21 days after the first application. Evaluations were made 15 and 30 days following the second application.

Atrazine, diuron, and karbutilate--a single application

The three residual herbicides were applied only once, the first week of July, and then evaluated after 15 and 45 days.

Dry Season Experiment

Herbicides react differently during the dry season than they do during the rainy season. Six herbicide treatments, each replicated four times, were applied April 5, 1972, using the same procedure as was used for the rainy season experiments. Table 7 shows the treatments. Average weed hieght was 60 centimeters. An evaluation was made after 8 days. A second evaluation was planned for 60 days, but the plots had been cut with machetes.

Table 7. Herbicides applied during the dry season

Herbicide	Grams or milliliters per treatment	kg/ha
Dalapon	86.0	10.0
MSMA	76.0	5.0
Cacodylic acid	240.0	10.0
Amitrole	244.0	8.0
Paraquat	31.0	1.0
Paraquat	62.0	2.0

Water Pollution Experiment

During the rainy season, an experiment was performed to see what effects large amounts of rain had on washing the herbicides from the vegetation. Forty by 1.8 meter plots on ditchbanks were sprayed with MSMA at 5 kg/ha, cacodylic acid at 10 kg/ha, and diuron at 12 kg/ha. Water samples of 40 ml were taken 100 meters downstream from the plots during rainstorms that occurred within 12 hours after application. Figure 3 shows one of the canals that was sprayed. The average weed height and the liters per second of water in each canal is reported in Table 8.

Figure 3. Los Patos Canal being sprayed for water pollution study

Table 8. Amount of flowing water and average weed height of the canals sprayed

Canal	Amount of water flowing in canal (liters/sec)	Average weed height (cm) Aug. 1971
Chucacato	521	25
Cuneta	70	60
Los Patos	400	75
Belen	500	90

Diuron

The water samples were analyzed chromatographically for herbicide residues using the experimental procedure of McKone and Hance (1969).

Ten ml of water was measured into a 250 ml separatory funnel and extracted for 1 minute each with two 10 ml portions of dichloromethane. The organic layers were collected in a separate 250 ml separatory funnel. The solution was concentrated to about .5 ml under reduced pressure on a water bath at 35 C. The remaining solvent was removed with a stream of air. Five ml of saturated sodium chloride solution was added and the flask was shaken for 15 seconds. Fifteen ml of 2,2,4-trimethylpentane was added and the flask shaken for 1 minute. Aliquots of the upper 2,2,4-trimethylpentane layer were taken and diluted for gas chromatography.

A Hewlett Packard 5750 gas chromatograph was used with a 1.8 m x 3 mm i.d. glass column packed with 3.5% DC 200 on GAS-CHROM Z 80-100 mesh. The injector temperature was 200 C, the detector 225 C, and the column 150 C.

A standard solution of diuron containing 1 mg/ml was prepared in redistilled methanol. Ten µl of the solution was transferred to a 25 ml volumetric flask and diluted with 2,2,4-trimethylpentane to 10 ml, making a 1 ppm solution containing 1 ng in 1 µl which was the injection volume. This solution was diluted to give a .5 ppm solution containing .5 ng in 1 µl.

A fortified solution of 1 ppm was obtained by diluting 1 ml of the 1 mg/ml diuron in methanol solution to 1 liter with distilled water. This solution was extracted to determine percent recovery.

Organic arsenicals

The water samples were analyzed for arsenic using an Instrumentation Laboratory 353 atomic absorption spectrophotometer.

A standard arsenic solution of 1000 ppm was made by diluting 4.95 ml of MSMA (20.2% elemental arsenic) to 1 liter of water. Ten ml of this solution was diluted to 1 liter giving a 10 ppm solution. Solutions of .5, 1, 2, and 3 ppm were prepared from the 10 ppm standard.

RESULTS AND DISCUSSION

Rainy Season Experiments

Contact, translocated, and residual herbicides--a single application

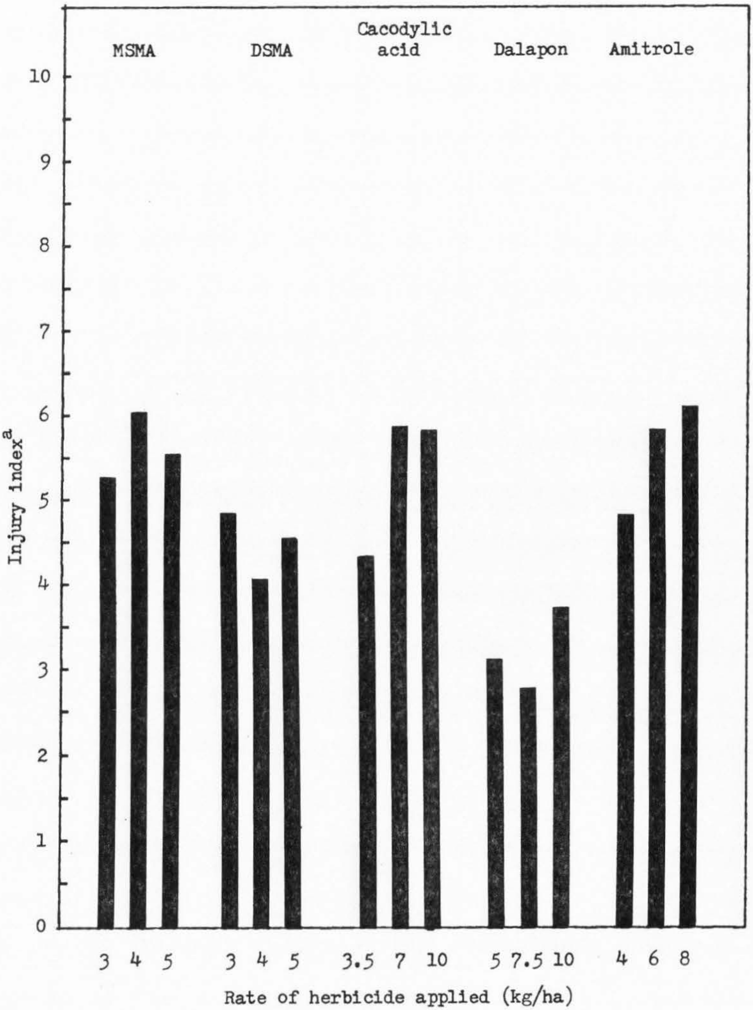
Several herbicides, including MSMA, cacodylic acid, amitrole, diuron, and karbutilate effectively reduced the growth of perennial grasses (Figures 4 and 5, Table 9). The average control of these treatments was 55 percent.

Dalapon was not very effective (37 percent control) due to the maturity of the grasses. McWhorter (1966) reported that dalapon was often ineffective on mature grasses. The two lower dosage levels of dalapon were significantly less effective than the higher levels of the other contact or translocated herbicides, with the exception of DSMA.

Lucas (1961), Hamilton (1969), and Kempen (1966) have reported DSMA to be less effective than MSMA on perennial grasses. We observed DSMA to be slightly less effective, but differences failed to show significance.

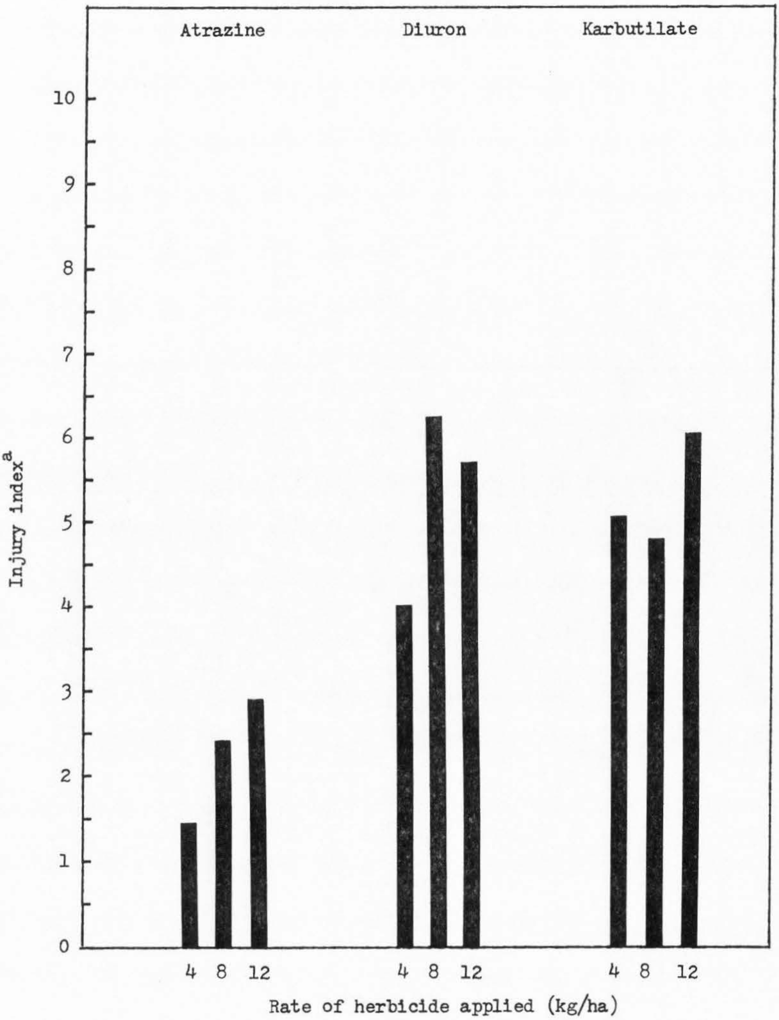
Cacodylic acid at the higher dosage levels killed all topgrowth within 2 days, but regrowth began after a period of about 1 week.

Atrazine, diuron, and karbutilate, the residual herbicides, are absorbed more readily through roots than through foliage. Atrazine did not control the weeds as well as did the other residual herbicides (Figure 5). This may be because atrazine was not absorbed as readily on low clay, low organic matter soils as were diuron and karbutilate and was, therefore, less readily available to the weeds. There were



[a]0 = no control 10 = complete control

Figure 4. Control of perennial grasses 15 days after a single application of contact and translocated herbicides



[a] 0 = no control 10 = complete control

Figure 5. Control of perennial grasses 15 days after a single application of residual herbicides

Table 9. Injury ratings on perennial grasses 15 days after a single application of contact, translocated, and residual herbicides

Treatment	Rate of herbicide applied (kg/ha)	Injury index[a]
MSMA	3.0	5.25 abcd
	4.0	6.00 ab
	5.0	5.50 abc
DSMA	3.0	4.75 abcde
	4.0	4.00 abcde
	5.0	4.50 abcde
Cacodylic acid	3.5	4.25 abcde
	7.0	5.75 abc
	10.0	5.75 abc
Dalapon	5.0	3.00 de
	7.5	2.75 e
	10.0	3.75 abcde
Amitrole	4.0	4.75 abcde
	6.0	5.75 abc
	8.0	6.00 ab
Atrazine	4.0	1.50 e
	8.0	2.50 e
	12.0	3.00 de
Diuron	4.0	4.00 abcde
	8.0	6.25 a
	12.0	5.75 abc
Karbutilate	4.0	5.00 abcd
	8.0	4.75 abcde
	12.0	6.00 ab

[a]Values followed by the same letter are not significantly different at the 5% level as determined by Newman-Keuls multiple range test. Each value is the mean of 4 replications.

heavy rains (225 mm in 11 days) soon after application which leached out the atrazine more readily than the other residual chemicals.

In this experiment, there is no relationship between dosage level of any herbicide and its ability to control perennial grasses.

Contact and translocated herbicides--2 applications

Greater control was observed after two applications of the herbicide treatments (Figure 6, Table 10).

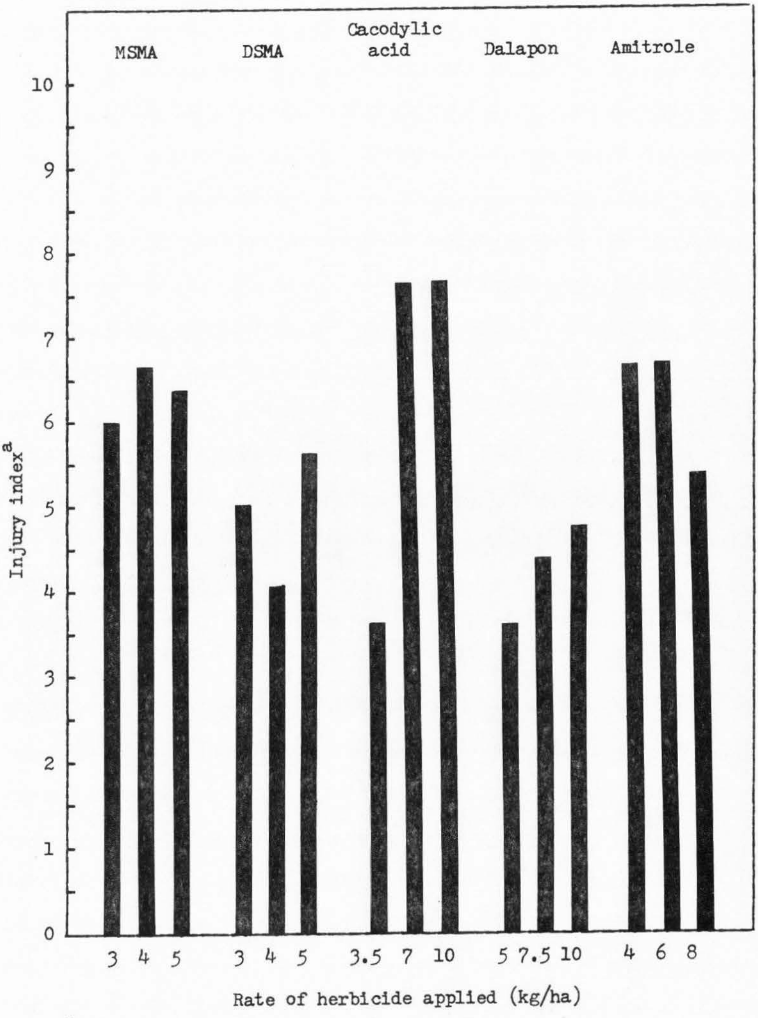
The 7 and 10 kg/ha treatments of cacodylic acid were the most effective treatments 15 days after the second application (77 percent control) and they were significantly better than the 3.5 kg/ha dosage. Sachs and Michael (1971) reported cacodylic acid to be more toxic than MSMA when foliar applied. Regrowth, however, began more rapidly with this herbicide than with the others.

MSMA and amitrole were effective in continued control of the grasses and were not significantly lower than the higher dosages of cacodylic acid.

DSMA was approximately 20 percent less effective than MSMA. Dalapon, although showing a 10 percent increase from the single application, was not nearly as effective as the other treatments.

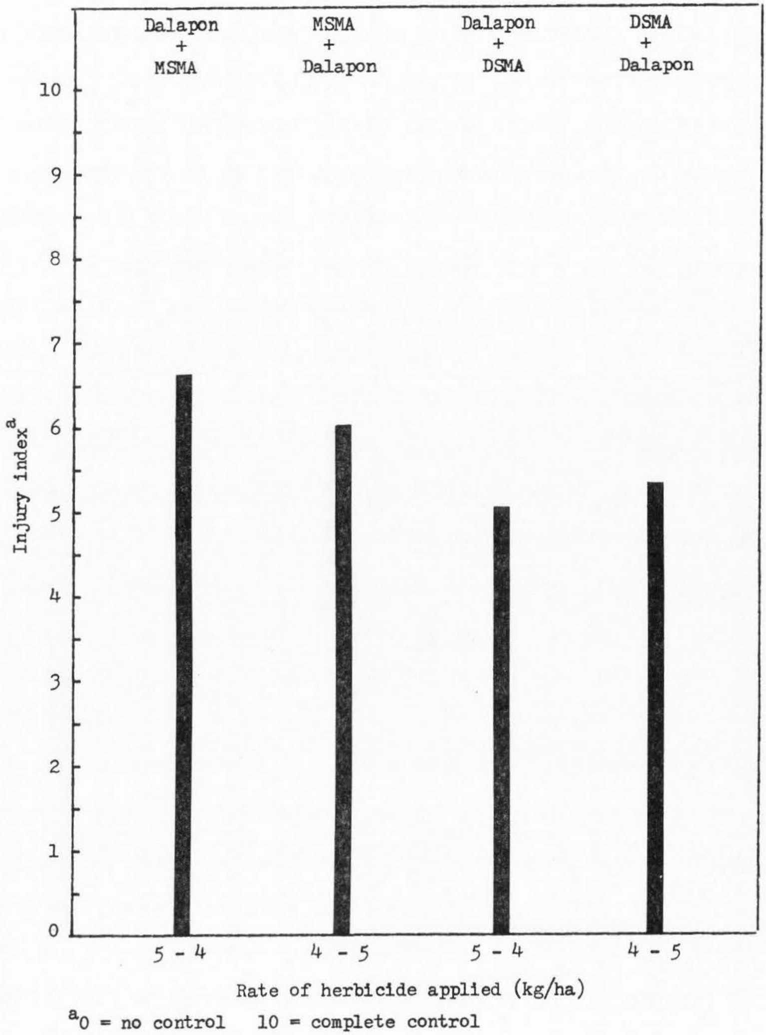
Figure 7 gives the results of alternating dalapon and organic arsenicals. The treatment of MSMA at 4 kg/ha, applied 21 days after an application of dalapon at 5 kg/ha, was the most effective treatment, although it did not exceed two applications of MSMA alone (Figure 6).

DSMA alternated with dalapon had no greater effect than DSMA alone. No real improvements were obtained by alternating dalapon and organic arsenicals.



[a]0 = no control 10 = complete control

Figure 6. Cumulative control of two applications of contact and translocated herbicides on perennial grasses 15 days after the second application



[a]0 = no control 10 = complete control

Figure 7. Cumulative control of dalapon alternated with organic arsenicals on perennial grasses 15 days after the second application

Table 10. Injury ratings after two applications of selected foliar herbicides on perennial grasses 15 days after the second application

Treatment	Rate of herbicide applied (kg/ha)	Injury index[a]
MSMA	3.0	6.00 abcd
	4.0	6.66 ab
	5.0	6.33 abc
DSMA	3.0	5.00 abcd
	4.0	4.00 cd
	5.0	5.66 abcd
Cacodylic acid	3.5	4.66 bcd
	7.0	7.66 a
	10.0	7.66 a
Dalapon	5.0	3.66 d
	7.5	4.33 bcd
	10.0	4.66 bcd
Amitrole	4.0	6.66 ab
	6.0	6.66 ab
	8.0	5.33 abcd
Dalapon + MSMA	5.0 + 4.0	6.66 ab
MSMA + Dalapon	4.0 + 5.0	6.00 abcd
Dalapon + DSMA	5.0 + 4.0	5.00 abcd
DSMA + Dalapon	4.0 + 5.0	5.33 abcd

[a]Values followed by the same letter are not significantly different at the 5% level as determined by Newman-Keuls multiple range test. Each value is the mean of 4 replications.

Dalapon and organic arsenicals--3 applications

MSMA most effectively controlled the vegetation after three applications (Figure 8, Table 11). The 5 kg/ha dosage produced 87 percent control, an increase of 24 percent over two applications. This agrees with Kempen's (1966) findings, that MSMA was more effective than either DSMA or dalapon.

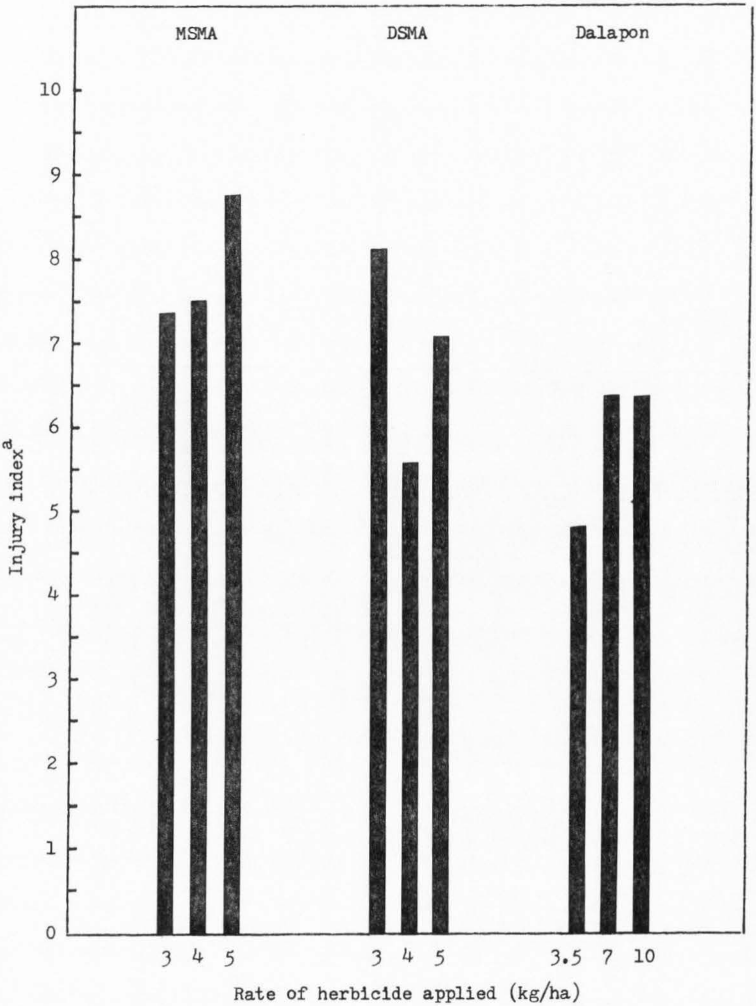
Treatments of dalapon increased from 37 percent with a single application to 62 percent after three applications. Much better control with dalapon could most likely be obtained by spraying earlier in the year when the vegetation is not as mature.

The weed control with alternating treatments of MSMA and dalapon did not exceed that of three applications of MSMA alone (Figure 9, Table 11). DSMA alternated with dalapon did not show increased control over DSMA alone, nor were its effects lessened by alternating it with dalapon. Hamilton (1969) found that DSMA combined or alternated with dalapon reduced the effectiveness of DSMA.

Eight months after spraying it was evident that where dalapon and organic arsenicals had been used, broadleaved weeds were the most predominant. This would suggest the need to follow up the control of grasses with non-selective herbicides, or herbicides selective for broadleaved weeds.

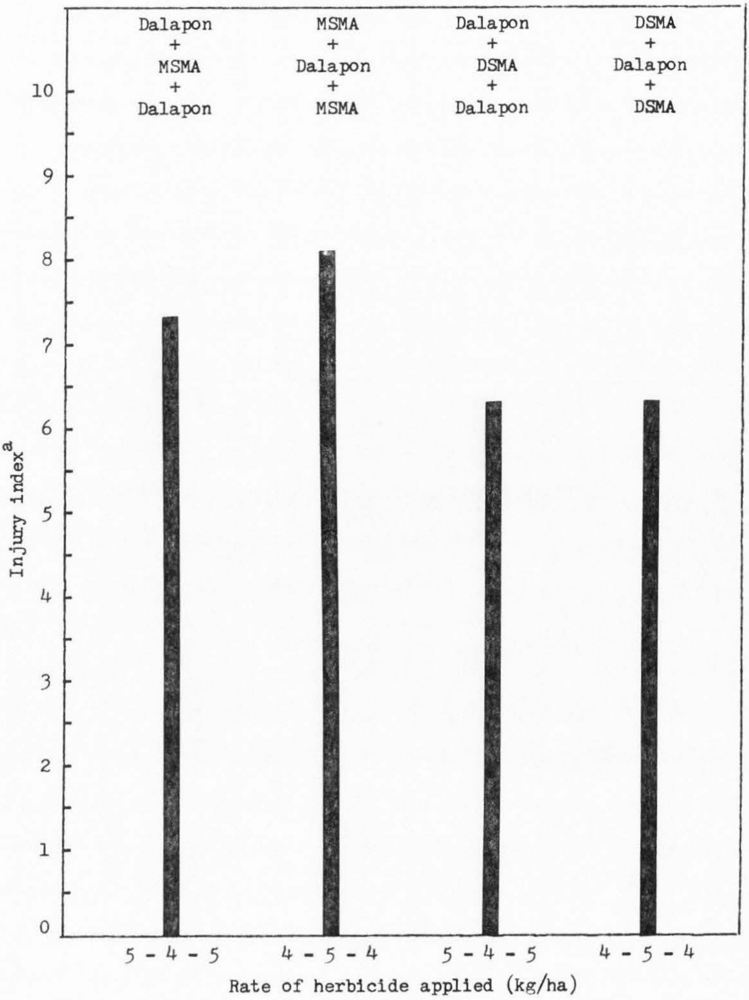
Amitrole and cacodylic acid--2 applications

The higher rates of cacodylic acid controlled the grasses much better than did the 8 kg/ha dosage level of amitrole when evaluations



[a]0 = no control   10 = complete control

Figure 8. Effects of three applications of dalapon, MSMA, and DSMA on perennial grasses 15 days following the third application



[a]0 = no control   10 = complete control

Figure 9. Effects of three applications of dalapon alternated with organic arsenicals on perennial grasses 15 days following the third application

Table 11. Effects of three applications of dalapon, MSMA, and DSMA on perennial grasses 15 days following the third application

Treatment	Rate of herbicide applied (kg/ha)	Injury index[a]
MSMA	3.0	7.25 abcd
	4.0	7.50 abc
	5.0	8.75 a
DSMA	3.0	8.00 ab
	4.0	5.50 defg
	5.0	7.00 abcde
Dalapon	3.5	4.75 g
	7.0	6.25 bcdef
	10.0	6.25 bcdef
Dalapon + MSMA	5.0 + 4.0	7.25 abcd
MSMA + Dalapon	4.0 + 5.0	8.00 ab
Dalapon + DSMA	5.0 + 4.0	6.25 bcdef
DSMA + Dalapon	4.0 + 5.0	6.25 bcdef

[a]Values followed by the same letter are not significantly different at the 5% level as determined by Newman-Keuls multiple range test. Each value is the mean of 4 replications.

were made 15 and 30 days following the second application (Figure 10, Table 12). The 7 and 10 kg/ha dosages of cacodylic acid resulted in 77 percent control after 15 days, which was significantly better than the 46 percent control of the 3.5 kg/ha dosage. Regrowth occurred rapidly with cacodylic acid whereas amitrole retarded regrowth. Control with the higher dosages of cacodylic acid dropped to 60 percent after 30 days. Weed control with the 4 and 6 kg/ha dosage of amitrole increased from 67 percent after 15 days to above 70 percent after 30 days. Control with the lower rates of amitrole was significantly higher than the 8 kg/ha dosage. This trend was noted in Figure 6. At the 8 kg/ha dosage level, amitrole may be acting as a contact herbicide and translocation may be inhibited.

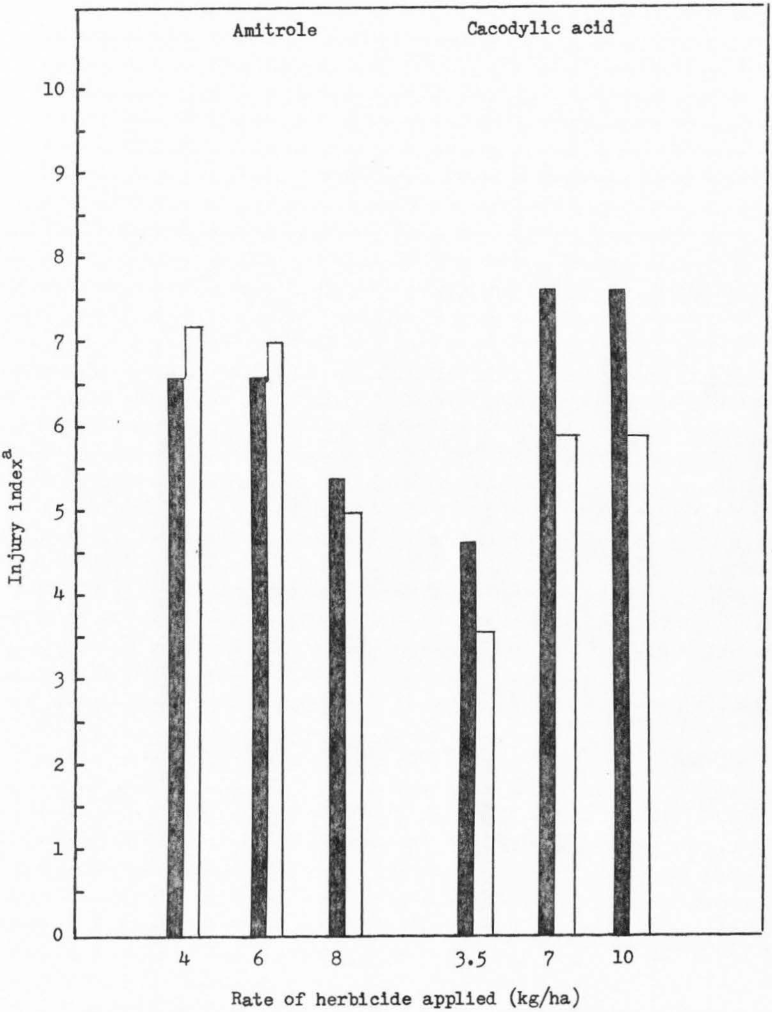
These findings agree with those of Bovey, Dowler, and Diaz-Colon (1969). They reported that cacodylic acid was an effective defoliant on guava (*Psidium guajava*) within 2 weeks after treatment, but that growth regulator-type herbicides were more effective 1 month after spraying.

Atrazine, diuron, and karbutilate--a single application

Diuron and karbutilate controlled the perennial grasses much better than did atrazine (Figure 11, Table 13).

After 45 days, control dropped off slightly with diuron, with 4 kg/ha of karbutilate, and with 8 and 12 kg/ha of atrazine.

Atrazine was not effective in controlling perennial grasses. This was probably due to the interaction of high temperature (see Table 2), high rainfall (see Tables 1 and 4), and lack of clay and organic matter in the soil. McCormick and Hiltbold (1966) found



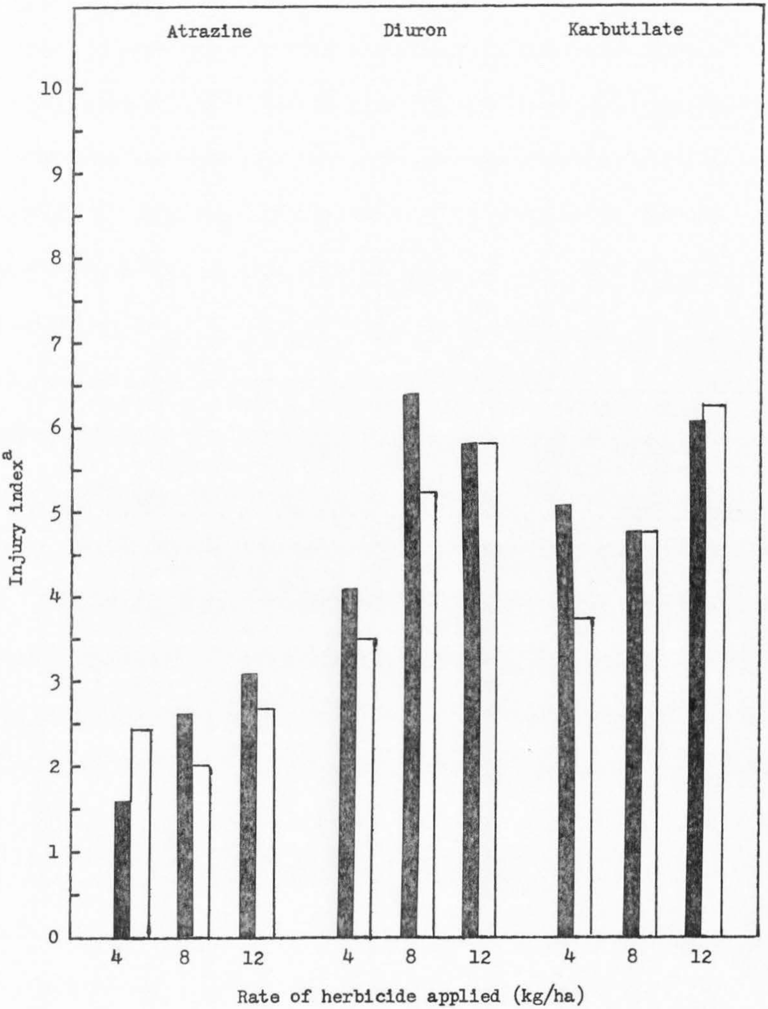
[a]0 = no control   10 = complete control

Figure 10. Cumulative control of two applications of amitrole and cacodylic acid on perennial grasses 15 days (solid column) and 30 days (open column) after the second application

Table 12. A comparison of the injury on perennial grasses with amitrole and cacodylic acid 15 and 30 days after spraying

Treatment	Rate of herbicide applied (kg/ha)	Injury index[a] 15 days	30 days
Amitrole	4.0	6.6 abcd	7.3 ab
	6.0	6.6 abcd	7.0 abc
	8.0	5.3 def	5.0 efg
Cacodylic acid	3.5	4.6 efg	3.6 g
	7.0	7.6 a	6.0 abcde
	10.0	7.6 a	6.0 abcde

[a]Values followed by the same letter are not significantly different at the 5% level as determined by Newman-Keuls multiple range test. Each value is the mean of 3 replications.



[a]0 = no control   10 = complete control

Figure 11. Control of perennial grasses 15 days (solid column) and 45 days (open column) after a single application of atrazine, diuron, and karbutilate

Table 13. Injury ratings on perennial grasses 15 and 45 days after a single application of atrazine, diuron, and karbutilate

Treatment	Rate of herbicide applied (kg/ha)	Injury index[a] 15 days	Injury index[a] 45 days
Atrazine	4.0	1.50 k	2.50 ghijk
	8.0	2.50 ghijk	2.00 jk
	12.0	3.00 ghij	2.75 ghijk
Diuron	4.0	4.00 defg	3.50 fghi
	8.0	6.25 a	5.25 abcd
	12.0	5.75 abc	5.75 abc
Karbutilate	4.0	5.00 abcde	3.75 efgh
	8.0	4.75 abcdef	4.75 abcdef
	12.0	6.00 ab	6.25 a

[a]Values followed by the same letter are not significantly different at the 5% level as determined by Newman-Keuls multiple range test. Each value is the mean of 4 replications.

that atrazine decomposition doubled for each 10 C rise in temperature up to 30 C. Klingman (1961) stated that where rainfall is greater than 35 inches per year and with relatively uniform monthly distribution, there exists little chance that atrazine will remain toxic from one year to the next. With rainfall near 70 inches, and distributed over 6 months, there is little chance it will remain toxic for more than 6 months.

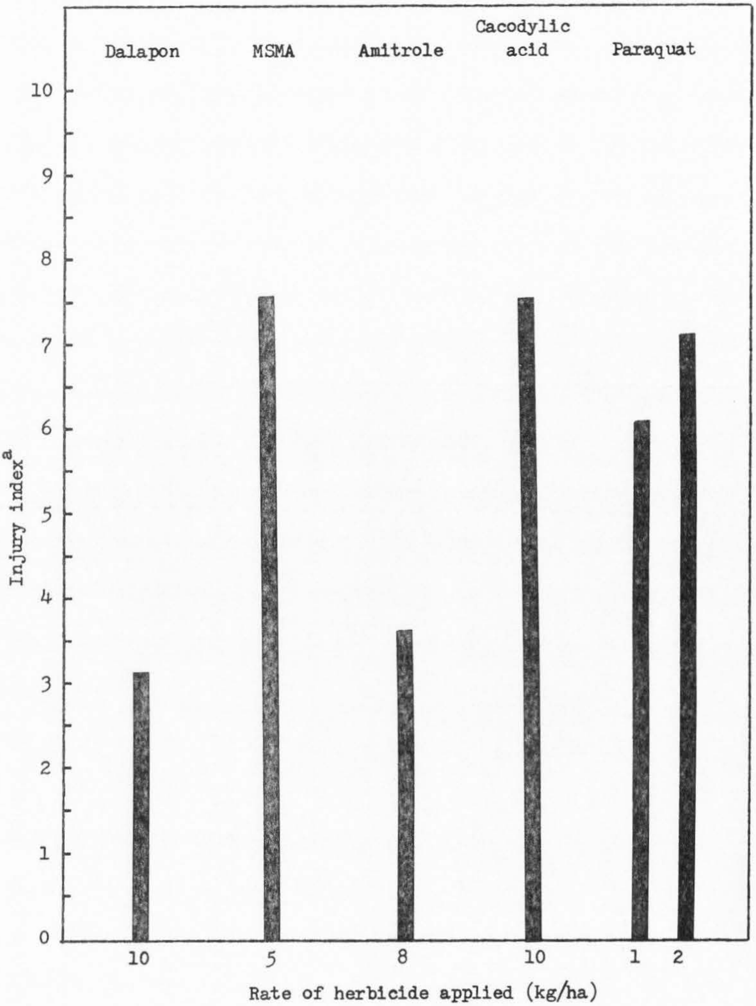
In April, 1972, 9 months after application, an evaluation was made of the residual herbicides. Two of the replications received considerable water due to irrigation and grasses were extremely high. No control was observed. On the two replications that had not received as much water, control was noticeable. Karbutilate at 12 kg/ha held back weeds considerably. Diuron at 12 kg/ha also maintained some control. Atrazine at 12 kg/ha resulted in more broadleaves than grasses.

Dry Season Experiment

MSMA, cacodylic acid, and paraquat were the most effective herbicides after 8 days (Figure 12, Table 14). MSMA and cacodylic acid showed 75 percent weed control and paraquat at 1 kg/ha produced 70 percent control.

Paraquat was extremely fast acting. Necrosis was apparent 2 hours after spraying, and after 1 day its effect appeared to be complete.

Dalapon was not effective at 10 kg/ha; only 30 percent control was obtained. This is in agreement to McWhorter (1966) who reported dalapon ineffective on mature johnsongrass and in dry seasons.



[a]0 = no control 10 = complete control

Figure 12. Control of perennial grasses 8 days after one application of contact and translocated herbicides

Table 14. Injury ratings on perennial grasses 8 days after one application of contact and translocated herbicides

Treatment	Rate of herbicide applied (kg/ha)	Injury index[a]
Dalapon	10.0	3.00 c
MSMA	5.0	7.50 a
Amitrole	8.0	3.50 bc
Cacodylic acid	10.0	7.50 a
Paraquat	1.0	6.00 bc
	2.0	7.00 ab

[a]Values followed by the same letter are not significantly different at the 5% level as determined by Newman-Keuls multiple range test. Each value is the mean of 4 replications.

Although amitrole showed little activity after 8 days, it would be expected that control would increase up to 30 days (see Figure 7) while the contact herbicides would most likely decrease.

An evaluation was planned for 60 days following application. However, before the evaluation could be made, the plots were cut by workers with machetes. Appendix 2 contains a special chapter on problems in working in foreign countries.

Water Pollution Experiment

Diuron

Samples were taken during four different rainstorms (Table 15). The highest concentration of diuron in the runoff water was 1.8 ppm (Table 16). This concentration occurred during a rainstorm which began .8 hours after application, continued for 30 minutes, and deposited 7.8 mm of water. Rain shortly after application caused the greatest washing of the herbicide since there was not sufficient time for it to be translocated into the plant. Intensity of the rain may determine whether the herbicide is leached into the soil or washed off into a water channel.

The majority of the samples analyzed contained less than .5 ppm of diuron. Chancellor (1958) found that concentrations up to 180 ppm are non-poisonous to man and livestock. Sills (1964) reported that diuron has a low acute toxicity to fish. Even at 1.8 ppm, the highest concentration of diuron in water that was found in this study, there is very little chance that injury to fish, livestock, or plants would result.

Table 15. Rainfall data for four different rainstorms during which water samples were taken for analysis

Storm	Date (1971)	Hours after herbicide application	Duration (hours)	Amount (mm)
1	Aug. 17	5.5	1.0	4.0
2	Aug. 18	6.0	.7	6.0
3	Aug. 21	14.0	1.7	33.0
4	Aug. 24	.8	.5	7.8

Table 16. Residue (ppm) of diuron in runoff water

Storm	Canal	Time[a]	Diuron[b]
1	Belen	30	less than .5
		60	" " .5
2	Chucacato	20	less than .5
		40	" " .5
3	Los Patos	15	.5
		30	.5
		45	less than .5
		60	" " .5
		90	" " .5
4	Cuneta	15	1.8
		20	.8
		25	.6
		30	less than .5
		35	" " .5
		40	" " .5

[a]Minutes after initiation of rainstorm
[b]Average of three determinations

Organic arsenicals

Samples were taken during four different rainstorms (Table 15). The sampling procedure and time intervals were approximately the same as those for diuron (see Table 16).

The atomic absorption spectrophotometer was sensitive down to levels of .5 ppm in water. Samples analyzed did not show arsenic levels to exceed .5 ppm. MSMA is 20.2 percent arsenic. To obtain a reading of .5 ppm of arsenic would require approximately 2.5 ppm of MSMA in water.

McKee and Wolf (1963) reported that arsenic may be toxic to certain fish if they are exposed to levels greater than 1 ppm for several days. Plants grown in water containing 1 ppm of arsenic trioxide show a blackening of the vascular bundles in the leaves.

As most of the herbicide that enters a channel does so during a rainstorm shortly after application, the only time water could contain amounts around 2.5 ppm would be during the storm itself. Fish or livestock would not be subjected to high levels over long periods of time.

Even if the water were used for irrigation, there is very little chance that any injury to crops would result.

SUMMARY

A study was conducted in El Salvador, Central America to determine the effects of selected herbicides on perennial grasses and water pollution under tropical, high rainfall conditions.

Several herbicides, including MSMA, cacodylic acid, paraquat, amitrole, diuron, and karbutilate satisfactorily controlled growth of perennial grasses. DSMA, dalapon, and atrazine were less effective.

Cacodylic acid was the most effective contact chemical with the dosages that were used. Regrowth began approximately 1 week after spraying. Amitrole was not as effective as cacodylic acid 2 weeks after spraying, but retarded regrowth and after 30 days showed better control than cacodylic acid.

No significant increase in control was obtained by alternating dalapon and organic arsenical herbicides.

Paraquat was applied only in the dry season. It was extremely fast acting and very effective in killing topgrowth.

Atrazine did not effectively control perennial grasses. High temperature, high rainfall, and the lack of clay and organic matter in the soil caused rapid leaching and decomposition of the herbicide.

A single application of diuron and karbutilate adequately controlled perennial grasses for 6 weeks.

Water samples were taken during rainstorms that occurred shortly after application of diuron, MSMA, and cacodylic acid. The low concentrations that were observed likely would not be hazardous to crops or animals.

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APPENDIXES

APPENDIX A

Table 17. Analysis of variance on injury index 15 days after a single application of contact, translocated, and residual herbicides

Source of variation	DF	SS	MS	F
Block	3	11.67		
Treatment	27	179.67	6.65	4.02**
Error	74	122.58	1.65	
Total	104	313.92		

**Significant at .01

Table 18. Analysis of variance on injury index 15 days after the second application of contact and translocated herbicides

Source of variation	DF	SS	MS	F
Block	2	7.68		
Treatment	18	72.98	4.05	2.29*
Error	36	63.65	1.76	
Total	56	144.31		

*Significant at .05

Table 19. Analysis of variance on injury index 15 days following the third application of dalapon and organic arsenicals

Source of variation	DF	SS	MS	F
Block	3	53.84		
Treatment	12	58.76	4.89	4.96**
Error	29	28.61	.98	
Total	44	92.76		

**Significant at .01

Table 20. Analysis of variance of injury index of two evaluations of amitrole and cacodylic acid

Source of variation	DF	SS	MS	F
Block	3	98.69	32.89	
Treatment	8	238.74	29.84	12.16**
Error A	24	58.88	2.45	
Time	2	1.12	.56	.93
Error B	6	3.61	.60	
Treatment x time	16	9.53	.59	1.14
Error C	48	25.05	.52	
Total	107	435.65	4.07	

**Significant at .01

Table 21. Analysis of variance on injury index of three evaluations of atrazine, diuron, and karbutilate

Source of variation	DF	SS	MS	F
Block	2	5.38	2.69	
Treatment	5	42.13	8.42	2.87
Error A	10	29.27	2.92	
Time	1	3.36	3.36	2.46
Error B	2	2.72	1.36	
Treatment x time	5	7.47	1.49	3.78*
Error C	10	3.94	.39	
Total	35	94.30	2.69	

*Significant at .05

APPENDIX B

Problem Areas of Working in Foreign Countries

Language and Communication

Without doubt, the language barrier is the largest obstacle with which one is faced. For most people it requires many, many years of living in the country to be able to truly communicate ideas and feelings and to understand sayings used in the everyday language. One who has little knowledge of the native language is severely handicapped, and cannot possibly be as effective in his mission as he would if he had a better understanding of the language.

Where one is dependent on native help, it is especially important that they understand what it is they are expected to do, and also that one understands what they are trying to communicate. If these conditions are not met, failure and frustration will be the result.

In El Salvador there are many people, mainly those outside the cities in agricultural areas, who have not had the opportunity of a good education. They cannot read or write and cannot be expected to comprehend much of what we often assume they do. There seems to be a large gap between the educated and the illiterate. An example of this is where engineers, foremen, and laborers work on the same project. Engineers give an order to the foremen, who in turn order the laborers. What the laborers end up doing is not always what the engineers ordered.

As my herbicide trials were near much-traveled roads, I was especially anxious that they not be disturbed. With this in mind, I explained and showed the engineers where my plots were, and that I was concerned that they be left alone so that evaluations could be made at a later date. They assured me that the plots would not be disturbed. However, at two different times workers cut out several plots with machetes. Somewhere there was a breakdown in communication.

In April of 1972, when I returned and made additional treatments during the dry season, I had large signs set at both ends of the treated area, saying, in effect, that beyond the signs were herbicide treatments and it was prohibited to cut the weeds. Once again, workers cut out many of the plots, making it impossible to obtain evaluations. They had been instructed to cut weeds on either side of the signs but did the opposite and cut between the signs. Here again, communication was inadequate.

Availability of Materials

Equipment and supplies are not as readily available as they are in the United States where agriculture is so much more advanced.

At one time during my research, part of the equipment we were using was either lost or stolen. With the help of a local chemical distributor, I was fortunate in obtaining a make-shift unit which was adequate.

Social-Economic

As government officials observed the effectiveness of the herbicide treatments in the Zapotitan Valley, the following question was asked: "If we implement on a large-scale basis the spraying of

ditchbank weeds with herbicides, what are all the laborers who are now cutting weeds with machetes going to do?"

Questions such as this one need to be dealt with realistically. Irving A. Tragen (1971) in an institutional development seminar given in El Salvador, emphasized the need of understanding all of the human, technical, political, social, cultural, and economic forces at work when we go in and try to help a country with its problems. Serious problems may result if we upset the balance of these forces.

VITA

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Master of Science

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